# The Illinois Basin — a tidally and tectonically influenced ramp during mid-Chesterian time

Janis D. Treworgy

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Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

*Cover Photo: Roadcut at intersection of I-64 and IN Hwy. 37 in Crawford County, Indiana. Formations pictured, from base up, are Big Clifty, Haney, and Hardinsburg.*

*Graphic Artist: Sandra K. Stecyk*

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# The Illinois Basin — a tidally and tectonically influenced ramp during mid-Chesterian time

Janis D. Treworgy

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ILLINOIS STATE GEOLOGICAL SURVEY
Morris W. Leighton, Chief
Natural Resources Building
615 East Peabody Drive
Champaign, IL 61820

FIGURES

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## ABSTRACT

As a result of subsurface and field studies, I identified major lithofacies of the mid-Chesterian (late Mississippian) Fraileys Shale/Big Clifty Sandstone and the Haney Limestone. In mapping the lateral and vertical distributions of the lithofacies, I found depositional and structural characteristics, most of which had not been recognized previously for the Illinois Basin during mid-Chesterian time:

1) The basin was a low-angle, low-relief ramp with an easterly sediment source during Fraileys/Big Clifty deposition and a northeasterly source during Haney deposition. The entire sequence thickens toward its southern extent in Illinois. Sandstone in the Fraileys/Big Clifty thickens toward the east. Coarse-grained carbonates in the Haney, including oolitic and skeletal grainstone, occur in a broad, shallow subtidal to low intertidal band along the western and eastern margins of the basin as well as on the Southern Shelf and grade downdip and offshore into progressively muddier facies. There is no evidence of a marked shelf edge.
2) The basin was tidally influenced with a dominantly westerly paleocurrent direction. Sandstone of the Big Clifty occurs as east-northeast trending offshore tidal bars that pinch out into and are capped by shale.
3) The basin was tectonically influenced as indicated by subtle facies and thickness changes across three major structural hingelines: the Du Quoin Monocline, the Rough Creek lineament, and the La Salle Anticlinal Belt. These structural hingelines had only minor relief during the mid-Chesterian and separated the somewhat deeper central part of the proto-Illinois Basin area from the shallower Western, Eastern, and Southern Shelves. The Southern Shelf appears to have formed a shallow sill on the Illinois Basin ramp. The ramp extended southward, reaching basinal depths beyond the present limit of the Illinois Basin.
4) The basin experienced three changes in relative sea level that affected sedimentation and the early diagenetic history of the sediments.

Understanding facies distributions is important because much of the oil that remains to be found in the Illinois Basin probably occurs in stratigraphic (i.e., facies-controlled) or combination stratigraphic/structural traps. Tidal bars of Big Clifty Sandstone on the Eastern Shelf are the most promising target for the interval studied. Coarse-grained facies of the Haney Limestone on the middle to upper ramp areas around the margins of the basin may yield hydrocarbons where porosity is developed locally and where traps may occur. This new interpretation of the Illinois Basin as a ramp during the mid-Chesterian provides a different perspective from which to study facies distributions throughout the Chesterian.

## OVERVIEW

The Mississippian Chesterian Series is the major hydrocarbon-producing series in the Illinois Basin. Swann (1963, 1964) originally interpreted the regional depositional setting of the Chesterian. Although there have been significant advances in geologists' understanding of depositional environments in recent years, these ideas have not been applied widely to the Chesterian of the Illinois Basin. I studied the depositional environments of the Fraileys/Big Clifty Sandstone and Haney Limestone (figs. 1, 2) because they constitute one of numerous transgressive-regressive cycles in the Chesterian and because they directly overlie a thin, laterally continuous limestone (the Beech Creek), which is a basinwide subsurface marker that approximates a time line. Knowledge of the depositional processes for sands and coarse carbonates and their distribution is essential for determining shape and orientation of potential reservoirs — a predictive tool in hydrocarbon exploration.

Lateral and vertical distributions of lithofacies of siliciclastic Fraileys/Big Clifty (also known as Jackson sand) and carbonate Haney (Golconda lime) Formations indicate that the Illinois Basin was a ramp covered by a shallow epeiric sea with a low-angle, southwest-trending paleoslope (<1° slope) and a low-relief sea floor during mid-Chesterian (late Mississippian) time. Carbonate facies distributions in the basin (fig. 10) are consistent with characteristic facies patterns for carbonate ramps (Ahr, 1973; Wilson, 1975; Read, 1985). Generally, shallow subtidal to low intertidal upper ramp facies are clean, coarse carbonate sands that become muddier and finer offshore in middle and lower ramp areas. The Chesterian epeiric sea opened and deepened to the south-southwest toward the open ocean, beyond the limit of the present day Illinois Basin area. Uplift of the Pascola Arch during Mesozoic time and subsequent erosion of at least 8000 feet (~ 2400 m) of Paleozoic sediment (Marcher and Stearns, 1962), including the entire Chesterian, has masked the southern extent of deposition and resulted in a more restricted basin appearance.

The proto-Illinois Basin was tidally influenced during deposition of these mid-Chesterian units. Tidal processes controlled the distribution of quartz sand in the Fraileys/Big Clifty and, presumably, of carbonate sand in the Haney. Offshore tidal sand bars in the Big Clifty, as mapped in the subsurface (Potter, 1962, 1963; Baker, 1980; Williams, Noger, and Gooding, 1982; Specht, 1985), occur in an east-northeast trend in the eastern half of the basin in Indiana and Kentucky, where they are relatively significant hydrocarbon producers.

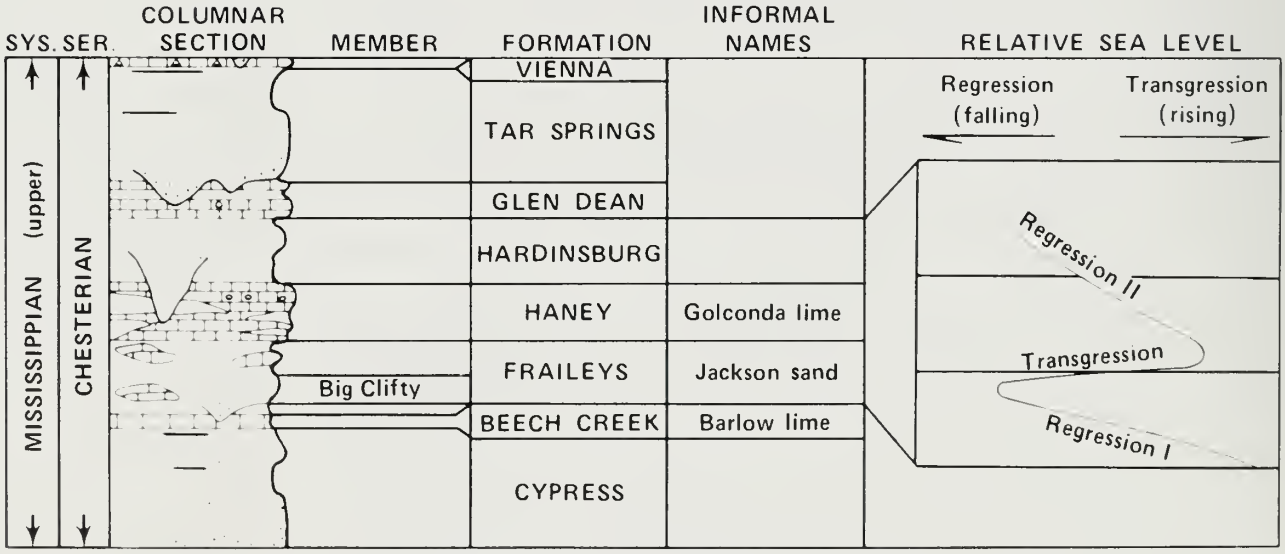


*Figure 1* *Columnar section of the mid-Chesterian in the Illinois Basin and relative sea-level fluctuations. Illinois nomenclature used. In the columnar section, the blank areas are shale. (Modified from Willman et al., 1975).*

Tectonism also influenced sedimentation in the Illinois Basin during the mid-Chesterian. Facies changes and thickness changes of units across three major structural hingelines, the Du Quoin Monocline, Rough Creek lineament, and La Salle Anticlinal Belt (fig. 3), indicate minor synsedimentary movement in the mid-Chesterian. These hingelines coincide with transitional facies boundaries between upper, middle, and lower ramp depositional settings.

Relative sea level fluctuated cyclically throughout the Chesterian and altered the relative influence of tidal and fluvial processes in basin sedimentation. Fluctuations in relative sea level also controlled the type and magnitude of early diagenetic cementation, which affects the reservoir quality of the rocks. Detailed lithofacies data collected in this study, including faunal changes, presence of paleosols, and textural changes in carbonate facies, document major changes in relative sea level for part of the mid-Chesterian.

The ramp configuration of the Illinois Basin, the tidal influence, and the mild synsedimentary tectonism documented in this study for two formations in the mid-Chesterian can be extrapolated to and tested on the entire Chesterian Series, which includes some of the major oil-producing zones in the Illinois Basin. The regional framework presented here will serve as a basis for local studies in the search for hydrocarbons.

Following a brief presentation of stratigraphic background and methods of study, I will discuss in more detail the major findings of this study. Then I will describe geographically the lithofacies distributions and interpreted depositional settings for the two formations, beginning on the eastern margin and moving west across the basin and then south of the Rough Creek lineament.

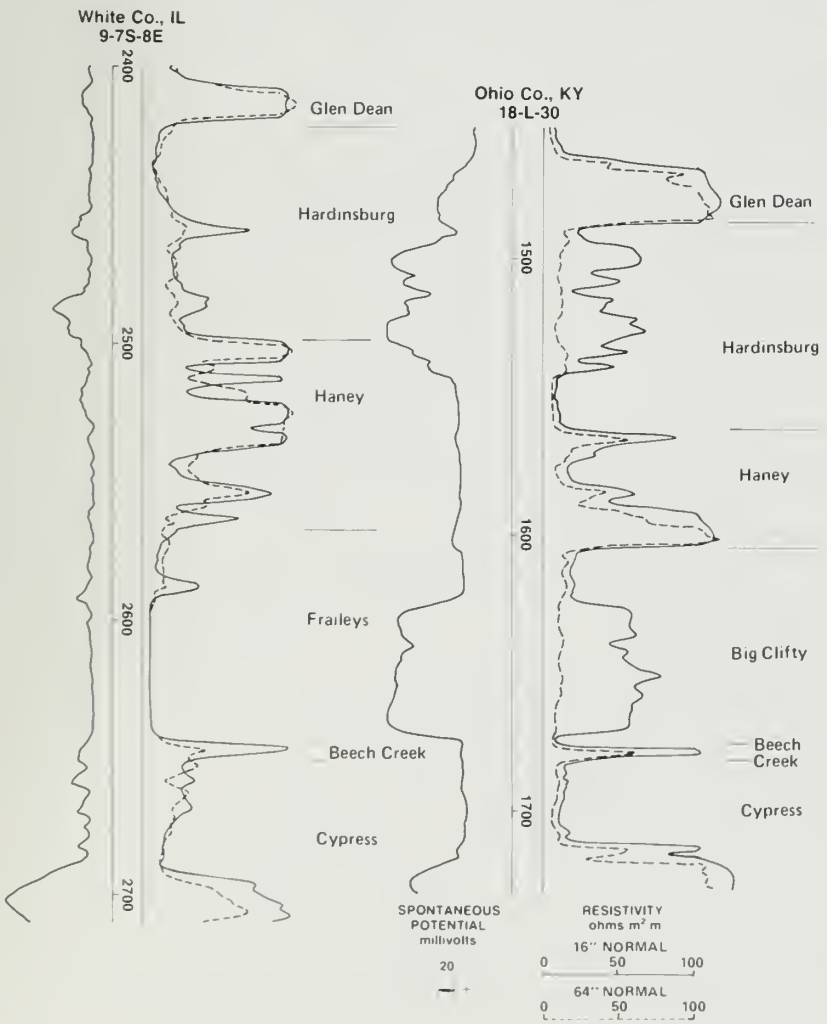


*Figure 2* *Typical electric logs of the mid-Chesterian. Log on left is from the central part of the basin and shows the shale facies of the Fraileys/Big Clifty. Log on right is from the Southern Shelf and shows the well-developed sandstone facies of the Fraileys/Big Clifty. The Fraileys/Big Clifty-Haney interval is thicker in the central part of the basin than on the Southern Shelf.*

## STRATIGRAPHIC RELATIONS

The Chesterian is the uppermost series of the Mississippian System. The Fraileys Shale/Big Clifty Sandstone and Haney Limestone, deposited during the middle part of the Chesterian (figs. 1, 2), cover an area of approximately 25,400 square miles (66,000 km$^2$) in the southern half of Illinois, in southwestern Indiana, and in western Kentucky (fig. 4). The units reach a combined maximum thickness of about 180 feet (55 m) in southernmost Illinois and thin northward toward their truncated edges (Willman et al., 1975).

In much of the western and central part of the Illinois Basin the Fraileys Formation is dominantly a dark gray shale with thin interbedded limestone. It


*Figure 3* *Major structural features in the Illinois Basin.*

grades eastward into a sandstone-shale unit, which is called the Big Clifty in Indiana and Kentucky (fig. 2). Sandstone in the Big Clifty thickens toward the east, suggesting an easterly sediment source and a north-northwest trending shoreline. The sand reaches a maximum thickness of 50 feet (15 m) in Indiana and 75 feet (23 m) in Kentucky, but is absent in places. Other lithofacies seen in cores and outcrops throughout the basin include siltstone, red and green mudstone, paleosols, and tempestites; they generally are not distinguishable on electric logs. The Fraileys/Big Clifty grades upward into the Haney Formation, which is a limestone interbedded with varying amounts of shale. The gradational contact transgresses time and may be difficult to identify locally.

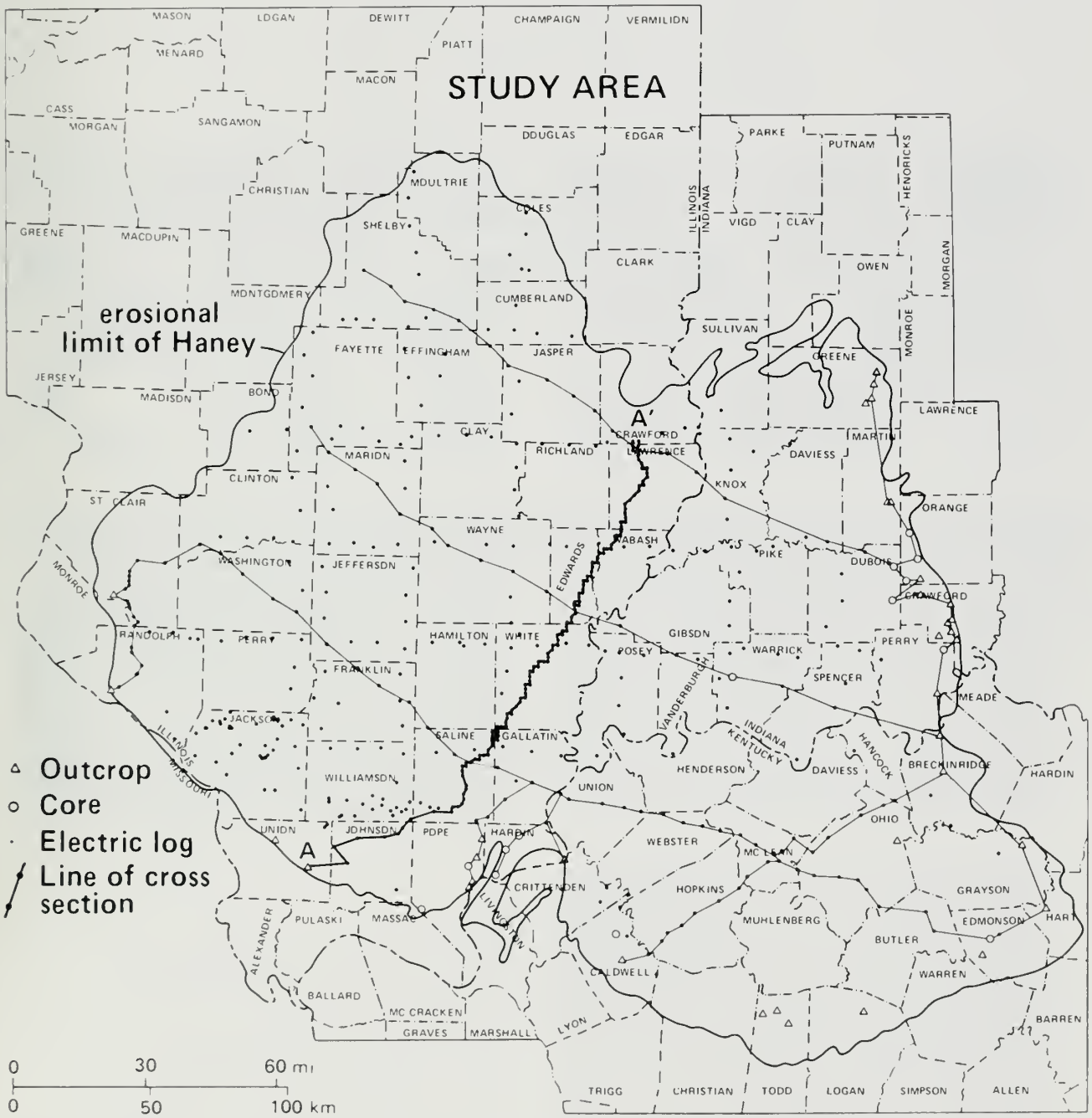


*Figure 4* *Study area, lines of cross sections (also see fig. 6 for section A-A'; this is the only section presented in this paper), and all datum points used in cross sections and lithofacies distribution maps (see figs. 9, 10). For cross-section A-A', only one well per section is shown; as many as eight wells per section were used where available.*

The Haney is white to light gray or brownish gray to dark gray skeletal packstone, skeletal grainstone, and oolitic grainstone; skeletal wackestone and carbonate mudstone also are present (fig. 5).

Carbonate beds in the Haney and Fraileys commonly contain abundant fossil fragments and, less commonly, whole fossils. The most abundant biotic components are bryozoans and echinoderms; also present are brachiopods, gastropods, bivalves, foraminifers, trilobites, ostracodes, corals, and calcareous algae. Abiotic constituents include ooids and superficial ooids, intraclasts, peloids, and detrital quartz. Interstitial material is generally micrite or sparry calcite cement. Micrite is commonly replaced by ferroan dolomite.

The Fraileys/Big Clifty-Haney interval is bounded by the Beech Creek Limestone (Barlow lime) below and the Hardinsburg Sandstone above (figs. 1, 2). The Beech Creek, a thin limestone that occurs throughout the Illinois Basin and beyond, is readily identifiable on electric logs and, therefore, provides a good basal marker for this study. It is overlain conformably by the siliciclastic Fraileys/Big Clifty.

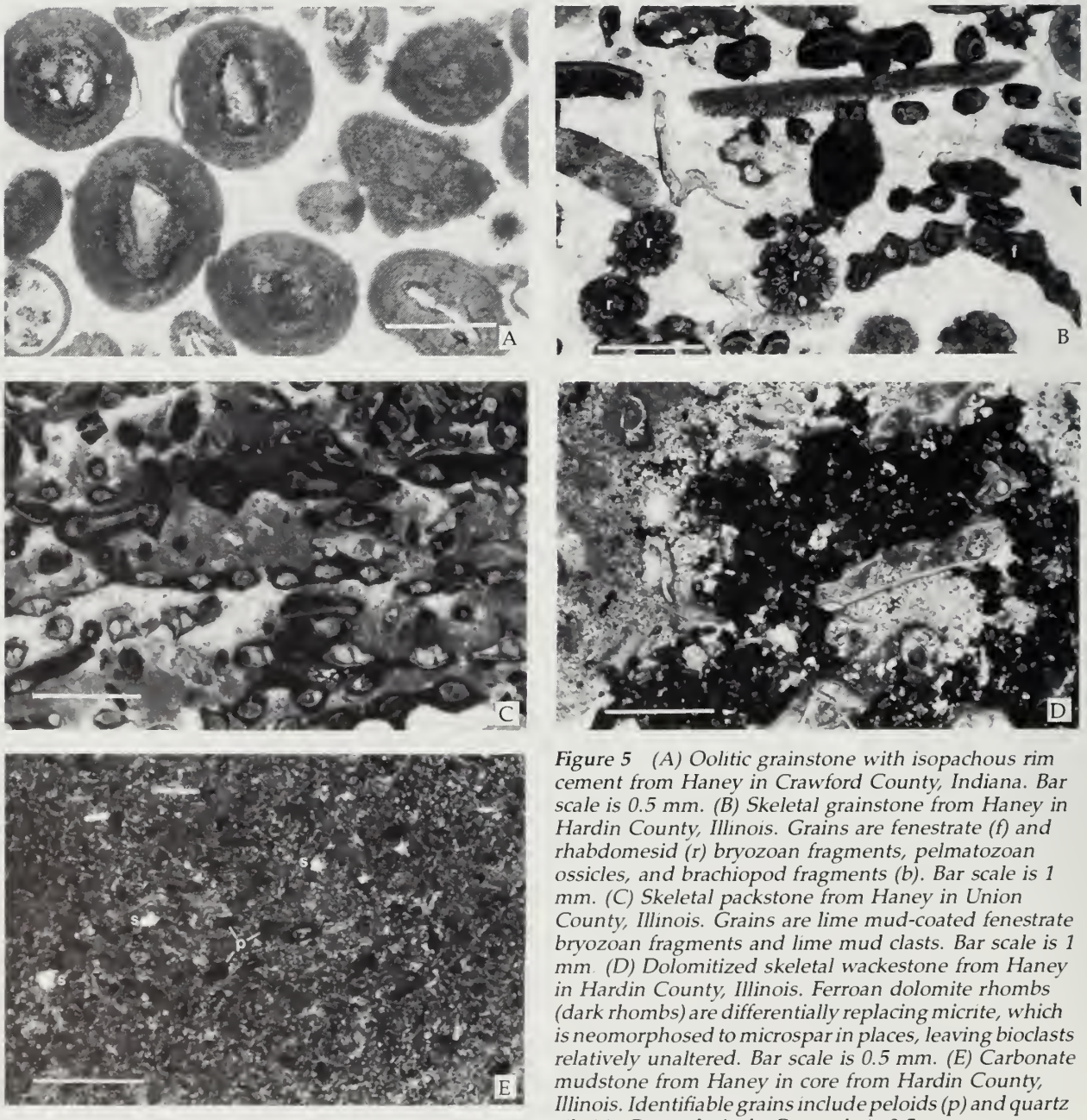


*Figure 5 (A) Oolitic grainstone with isopachous rim cement from Haney in Crawford County, Indiana. Bar scale is 0.5 mm. (B) Skeletal grainstone from Haney in Hardin County, Illinois. Grains are fenestrate (f) and rhabdomesid (r) bryozoan fragments, pelmatozoan ossicles, and brachiopod fragments (b). Bar scale is 1 mm. (C) Skeletal packstone from Haney in Union County, Illinois. Grains are lime mud-coated fenestrate bryozoan fragments and lime mud clasts. Bar scale is 1 mm. (D) Dolomitized skeletal wackestone from Haney in Hardin County, Illinois. Ferroan dolomite rhombs (dark rhombs) are differentially replacing micrite, which is neomorphosed to microspar in places, leaving bioclasts relatively unaltered. Bar scale is 0.5 mm. (E) Carbonate mudstone from Haney in core from Hardin County, Illinois. Identifiable grains include peloids (p) and quartz silt (s). Crossed nicols. Bar scale is 0.5 mm.*

The base of the Hardinsburg marks the change from the carbonate-rich conditions that prevailed during deposition of the Haney to a time of pronounced siliciclastic influx. The Haney-Hardinsburg contact is apparently conformable throughout the basin except where thick Hardinsburg sand locally cuts unconformably into the Haney (Swann and Atherton, 1948; Potter, 1963).

## METHODS OF STUDY

In this study I related facies observed in the subsurface throughout the Illinois Basin to detailed lithologic, faunal, and sedimentologic features seen in outcrops around the edge of the basin. I constructed a series of cross sections across the Illinois Basin using 720 electric logs, 112 sample studies, 13 cores, and 27 outcrops (fig. 4) (Treworgy, 1985). Thin sections were made of limestone cuttings from 156 samples in Illinois. Some 200 thin sections were made of outcrop and core samples, mostly from the Haney Formation. Dunham's (1962) classification was used in describing carbonate lithologies. All cross sections were constructed using the top of the Beech Creek Limestone as datum. These cross sections provided the basis for determining lateral and vertical distribution of lithofacies in this study.

A highly detailed section (A-A', fig. 6) was constructed using 371 electric logs, every hole available along the section's trend. Twenty-seven sample studies and one outcrop were also used in construction of the section. The section extends north-northeastward from southernmost Illinois to southern Crawford County, Illinois, where Pennsylvanian channels cut into the Haney and Fraileys. This line of section runs roughly perpendicular to the Chesterian shoreline postulated by Swann (1963, 1964) and, therefore, approximately perpendicular to regional depositional strike.

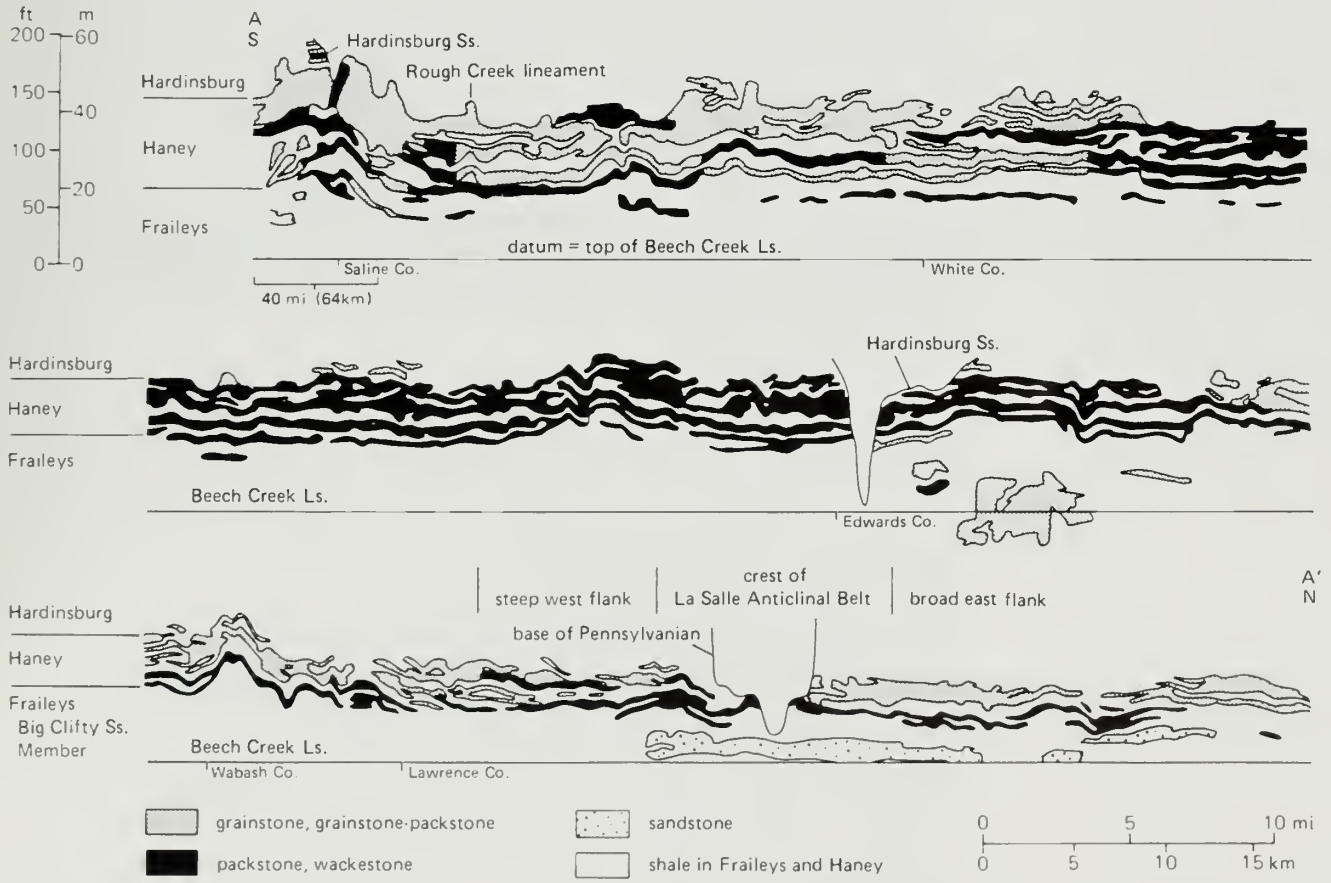


*Figure 6* *Southwest-northeast cross section A-A' of the Southern Shelf and central part of the Illinois Basin (also see fig. 4). Data include 1 outcrop and 371 electric logs; samples were studied for 27 wells. Datum is top of Beech Creek Limestone. Horizontal scale at south end is more compressed than the rest of the section.*

## CARBONATE RAMP

During Fraileys/Big Clifty and Haney deposition the Illinois Basin was a homoclinal ramp, according to terminology developed for shallow carbonate depositional basins by Ahr (1973), Wilson (1975), and Read (1985). In this report, I refer to the shallower areas of the ramp as shelves, after terminology of Wilson (1975, p. 21). Facies patterns observed in the Haney are characteristic of carbonate ramps:

- Clean, relatively coarse-grained grainstone and grainstone-packstone facies occur along the western and eastern shoreward subtidal to low intertidal margins of the Illinois Basin as well as along the shallow sill on the Southern Shelf.
- Facies grade downdip and offshore into progressively muddier facies — packstone and some wackestone — toward the central part of the basin (fig. 6).
- Facies occur over broad areas and grade laterally into other facies with no pronounced change in thickness (fig. 6).
- No evidence of a marked break in slope or of a narrow linear trend of reef or carbonate sand facies was seen.
- Gravity-flow deposits containing clasts of cemented shallow-shelf rocks, which occur on seaward slopes of carbonate platforms, were not encountered in cores or outcrops. Core and outcrop data are limited, however, to the shelves where this facies would not be expected to occur.

The distinction between carbonate ramps and platforms is not absolute because ramps can develop into platforms (Wilson, 1975; Read, 1982; James and Mountjoy, 1983; Read 1985). This transition would occur because of high carbonate production along the developing shelf edge where light, energy, and nutrient conditions are optimum for carbonate fixation. The Haney ramp, however, did not develop into a carbonate platform. One plausible explanation is that shale occurs as widespread, sheetlike bodies interbedded with limestone in the Haney (fig. 6); periodically fine-grained siliciclastics entered the basin and were widely distributed by tidal currents, filling in low areas and smoothing out the sea floor, including incipient shelf rims.

Shale beds in the Haney associated with micritic carbonate facies — those in the lower ramp area — are thicker and more laterally persistent than those associated with grainstone where agitated waters inhibited suspension sedimentation. Periods of relatively high siliciclastic influx were followed by periods of low siliciclastic influx during which laterally continuous limestone was deposited— a pattern characteristic of lower ramps (Read, 1980; Wilson, 1975).

## TIDAL INFLUENCE

Tidal influence in the Illinois Basin during mid-Chesterian time has been deduced primarily from other studies done on the Big Clifty Sandstone. Sandstone beds in the Big Clifty generally are lenticular (fig. 6), except along the eastern outcrop belt where they appear more continuous. Subsurface mapping (Potter, 1962, 1963; Baker, 1980; Williams, Noger, and Gooding, 1982; Specht, 1985) shows the elongate sandstone bodies to trend approximately east-northeast (fig. 7). These workers have interpreted the sandstone "pods" and "ribbons" (Potter, 1963) to be offshore tidal bars. Sandstone bars commonly pinch out into and are capped by shale, which could serve as a trap for hydrocarbons.

Outcrop studies of the Big Clifty (Potter et al., 1958; Visher, 1980) indicate that the siliciclastics along the eastern edge of the Illinois Basin were deposited nearshore in a tide-dominated deltaic environment. This interpretation is based on sedimentary structures, grain-size variation, paleocurrent patterns, and dominant sand-body orientations. Potter et al. (1958) reported a dominantly westerly paleocurrent direction based on cross-bedding data along the southern Kentucky outcrop belt. The westerly direction is perpendicular to their postulated shoreline, which derives from an easterly sediment source, and indicates tidal influence.

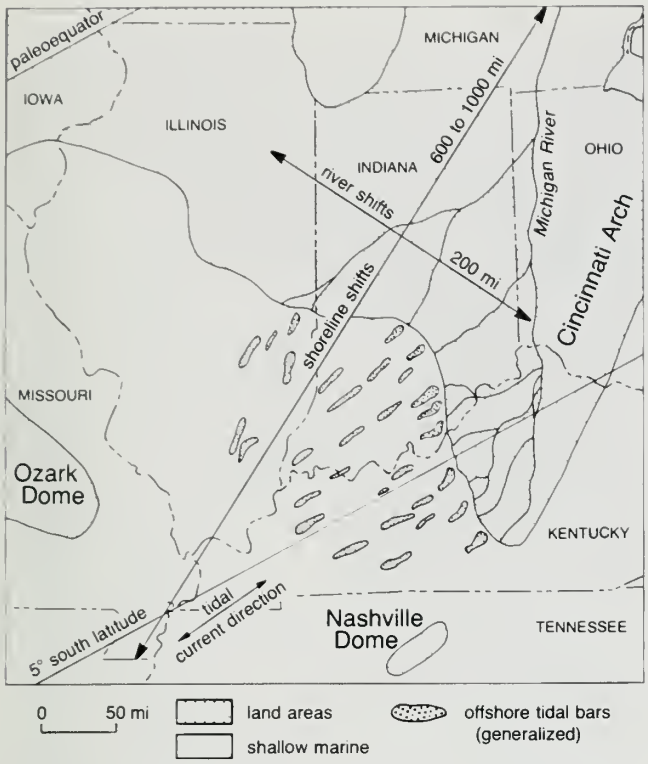


***Figure 7*** *Schematic paleogeographic view of the Illinois Basin during deposition of the Fraileys/Big Clifty Formation (adapted from Swann, 1963).*

## FLUCTUATIONS IN RELATIVE SEA LEVEL

Fluctuations in relative sea level affected depositional and diagenetic processes throughout the Illinois Basin. Three fluctuations in relative sea level identified in this study (fig. 1) are useful for extrapolating the vertical sequence of facies from one area to another, correlating within formational units, and hypothesizing early diagenetic environments.

The Beech Creek Limestone at the base of the Fraileys/Big Clifty-Haney interval is a muddier carbonate than the Haney Limestone and contains conodonts *(Gnathodus)* that are thought to occur basinward of nearshore, shallow-water shelf conodonts *(Cavusgnathus)* found in the Haney (Druce, 1973; Merrill, 1973; Merrill and von Bitter, 1976; Austin, 1976; von Bitter, 1976; R. D. Norby, personal communication, 1984). On the basis of this evidence, I interpreted the depositional setting of the Beech Creek as mostly lower ramp.

Exposure features seen in outcrops and cores of the upper part of the Fraileys/Big Clifty indicate that the Illinois Basin experienced a relative lowering of sea level sometime after the end of Beech Creek Limestone production. One explanation is that relative sea-level lowering began with the influx of siliciclastics at the beginning of Fraileys/Big Clifty deposition and slowly continued until it reached its lowest point near the end of the Fraileys/Big Clifty deposition (fig. 1, Regression I). Visher (1980), in her study of a large road cut near Sulphur in Crawford County, Indiana, found no evidence of any oscillation or sudden change in sea level during Big Clifty deposition; rather, she reported a shallowing-upward sequence in which exposure features, including wrinklemarks and mudcracks, are common in the upper 15 feet (4.6 m). Exposure features are common throughout the eastern outcrop belt in Indiana and Kentucky, usually directly above the sandstone. In many cores and outcrops in the eastern outcrop belt there are rip-up clasts, limestone conglomerates and nodules, fractures, and/or red and green mudstones just above the sandstone near the top of the Big Clifty.


***Figure 8*** *Negative print of thin section of a nodular paleosol from upper Fraileys/Big Clifty in Caldwell County, Kentucky. Note laminated intraclasts, brecciation, and desiccation cracks.*

Evidence of emergence in the upper part of the Fraileys/Big Clifty is not restricted to the shoreline or nearshore part of the Illinois Basin where lateral migration of a distributary channel could be the cause. In this study, paleosols and supratidal sediments also were identified in cores and outcrops along the Southern Shelf. In the field, these occurred as thin nodular carbonates (fig. 8) that were intraclastic, desiccated, laminated, dolomitic, and interbedded with red and green mudstone. Core or outcrop data in the upper part of the Fraileys are lacking for the central part of the basin, Western Shelf, and offshore western part of the Eastern Shelf. The Western Shelf may have been exposed subaerially at this time because it appears to have been fairly shallow during earlier Fraileys deposition. In the subsurface in deeper offshore areas of the Illinois Basin, red and green mudstone and shale near the top of the Fraileys/Big Clifty were seen in cuttings in this study and have been reported (Rose, 1963; Willman et al., 1975; Baker, 1980; Williams, Noger, and Gooding, 1982). The facies may represent sedimentation resulting from erosion of exposed mud flats on the surrounding shelves, but their origins remain uncertain.

The contact of the dominantly siliciclastic Fraileys/Big Clifty with the carbonate and siliciclastic Haney is transitional. The upper shale in the Fraileys/Big Clifty commonly is calcareous, contains normal marine fossils, and in Illinois, includes laterally discontinuous thin limestone beds (fig. 6). The base of the Haney commonly is marked by the first occurrence of relatively thick, laterally

continuous limestone, which is generally a lower ramp packstone-wackestone. The lithologic transition from the time of shelf emergence, in the latter part of the Fraileys/Big Clifty, to deposition of the basal, relatively muddy carbonate of the Haney represents a rather sharp rise in sea level (fig. 1, Transgression).

The vertical sequence of lithofacies within the Haney varies throughout the Illinois Basin, but lithofacies along the flanks of the basin generally become less muddy upward (fig. 6) — a trend interpreted as shallowing upward. This trend is supported by the occurrence of a few specimens of the deeper water conodont, *Gnathodus*, in the base of the Haney at some localities, along with many specimens of the shallow-water conodont, *Cavusgnathus*. No *Gnathodus* has been found in the remaining upper section of the Haney, which, as in the base of the Haney, contains many specimens of *Cavusgnathus* (R. D. Norby, personal communication, 1985, based on collection of Rexroad and Jarrell, 1961, from outcrops used in this study). The general shallowing-upward depositional pattern indicates a reversal of relative sea-level change some time during early Haney deposition (fig. 1). Throughout the remainder of Haney deposition, relative sea level fell slowly (fig. 1, Regression II); therefore, the Haney is an offlap or regressional sequence.

The Haney-Hardinsburg transition is marked by a basinwide influx of siliciclastics, which initially were suspension-load siliciclastic mud and, in places, sand that stifled carbonate production. In places, the shale is fossiliferous and includes limestone stringers, indicating a transitional period from high carbonate production in the Haney to restricted and eventually no carbonate production in the Hardinsburg due to the abundance of siliciclastic mud in the water column. The Hardinsburg Formation represents a progradational period that began with the initial influx of the siliciclastics and persisted long enough for sand to move across the entire Illinois Basin (Potter, 1963). The accompanying relative fall in sea level resulted in emergence of most of the basin (Swann, 1963).

The fact that Haney deposition was succeeded by a period of progradation and emergence indicates that Haney carbonates were exposed early to meteoric water in the phreatic zone. Petrographic evidence seen in this study for this interpretation is reduced porosity due to the presence of early marine cement rims and pervasive cementation by blocky calcite that formed prior to compaction (Heckel, 1983; Longman, 1980) (figs. 5a, b). Examples of blocky calcite include syntaxial overgrowths on echinoid fragments and interlocking crystals of equant calcite that coarsen toward pore centers. The Haney, particulary the coarse-grained facies, appears to be tightly cemented.

## TECTONIC INFLUENCE

Structural features within the Illinois Basin, including the Du Quoin Monocline, the Rough Creek lineament, and the La Salle Anticlinal Belt (fig. 3), underwent minor deformation that altered lithofacies distributions during mid-Chesterian time. Broad areas adjacent to these structural features, including the central part of the basin and the Western, Eastern, and Southern Shelves, appear to have been relatively distinct depositional environments reflecting their relative positions on the ramp. Synsedimentary tectonism is further evidenced by thinning of units on the high west side of the Du Quoin Monocline and on the La Salle Anticlinal Belt, which is a monoclinal feature with its high side to the east-northeast.

Mapping the distribution of the basic lithofacies of the Fraileys/Big Clifty and Haney (figs. 9, 10) generally shows that throughout Fraileys/Big Clifty-Haney deposition the central part of the Illinois Basin area appears to have been somewhat deeper than all marginal areas, including the Southern Shelf, which appears to have been a broad, shallow sill. Transitions between shallow shelf and deeper areas, as defined by lithofacies, are gradual, but generally coincide with structural hingelines, indicating that paleotectonics influenced sedimentation.

## DISTRIBUTION OF LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS

### Eastern Shelf

**Fraileys/Big Clifty** Sandstone in the Big Clifty occurs approximately in the area of the Eastern Shelf and extends into east-central Illinois along the northern part of the study area (fig. 9, 6). Sandstone on the Eastern Shelf is laterally discontinuous; it thickens and becomes more widespread to the east, indicating an easterly sediment source. Most Chesterian siliciclastics, including the Hardinsburg Formation that directly overlies the Haney, apparently entered the Illinois Basin from the northeast via the Michigan River of Swann (1963). A lateral shift of the river to the southeast, as suggested by Swann (1963), would permit sediments to enter the basin along an eastern shoreline. During Big Clifty deposition, the major distributary channel could have reached Kentucky, confined on the east by the Cincinnati Arch (fig. 7). Subsidiary distributary channels may have discharged sediment into the basin farther north in Indiana and possibly Illinois.

At the eastern edge of the Illinois Basin in Crawford County, Indiana, (fig. 4) the Big Clifty has been interpreted in outcrop as a shallowing-upward sequence that extends from marginal subtidal at the base to low intertidal flat deposit near the top where evidence of emergence is abundant (Visher, 1980). Evidence of subaerial exposure elsewhere in the basin supports a relatively widespread but short-lived emergence during late Big Clifty deposition. The

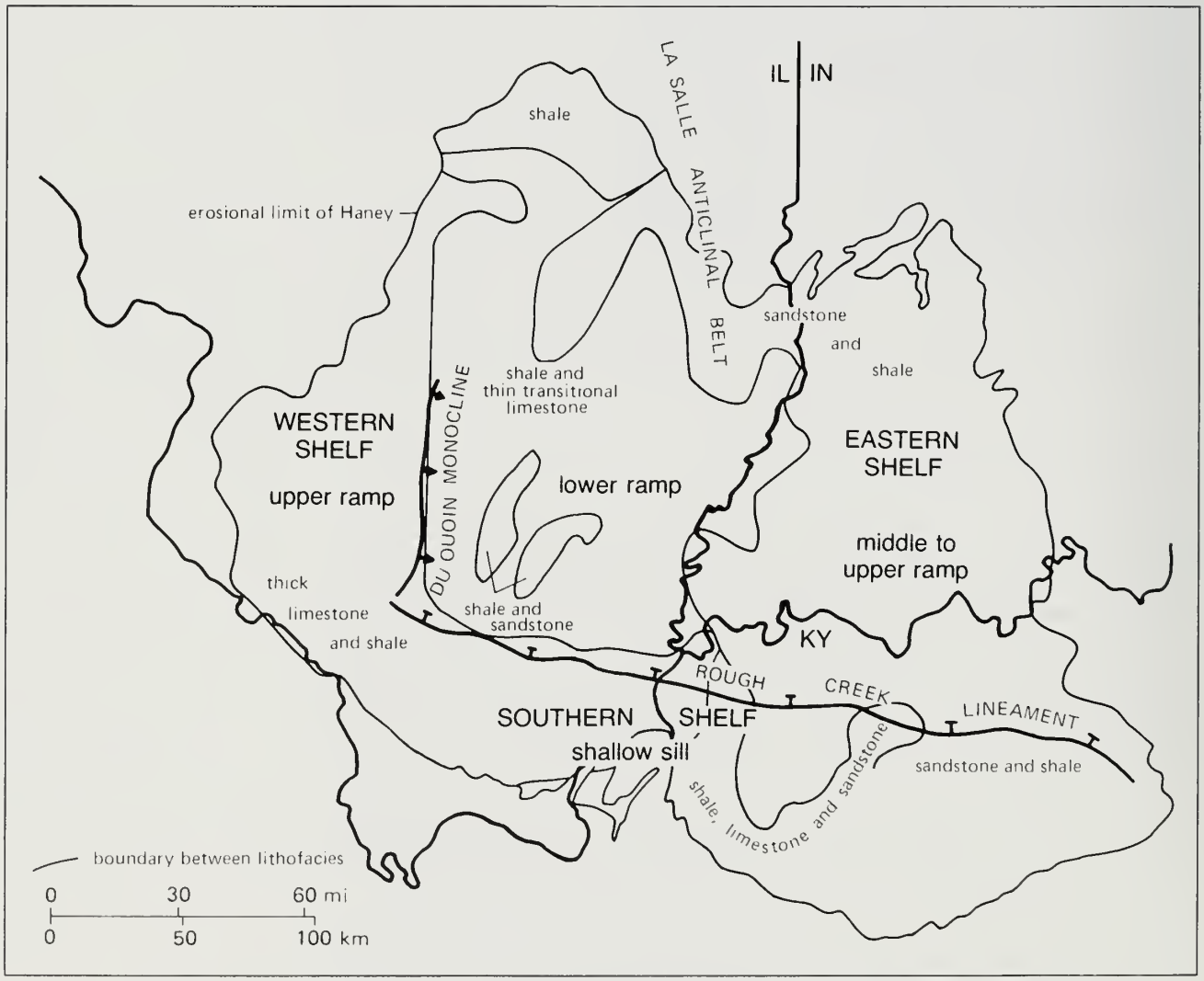


*Figure 9* *Lithofacies and depositional environments of the Fraileys/Big Clifty Formation and their relation to structural features in the Illinois Basin. Lithofacies are presented in order of abundance in each area.*

sedimentary record of any channel and upper delta plain of the Michigan River at that time has been eroded by subsequent uplift and erosion of the Cincinnati Arch and adjacent areas.

Farther west on the Eastern Shelf, lenticular sand bodies mapped in the subsurface have been interpreted as shallow marine tidal bars (Potter, 1962, 1963; Baker, 1980; Specht, 1985). The Eastern Shelf presumably deepened somewhat toward the central part of the basin, as indicated by increased thickness of the Fraileys/Big Clifty toward that area.

Shale overlying the sandstone throughout the eastern outcrop belt and basinward represents reduction in sediment supply to the basin in the latter part of the Fraileys/Big Clifty deposition. An abundantly fossiliferous shale above the sandstone near Sulphur, Indiana (Kelly, 1984), marks the return of marine subtidal conditions as well as a reduction of siliciclastic influx at the shoreward edge of the Illinois Basin. The fossiliferous shale grades upward into the Haney Limestone, which marks the first occurrence of relatively thick, laterally continuous limestone.

**Haney** Limestone in the Haney is a muddy carbonate, generally packstone and packstone-wackestone on much of the western part of the Eastern Shelf. This lithofacies represents deposition relatively far offshore on the lower ramp, below effective wave base — a somewhat deeper environment than during Fraileys/Big Clifty deposition (fig. 10).

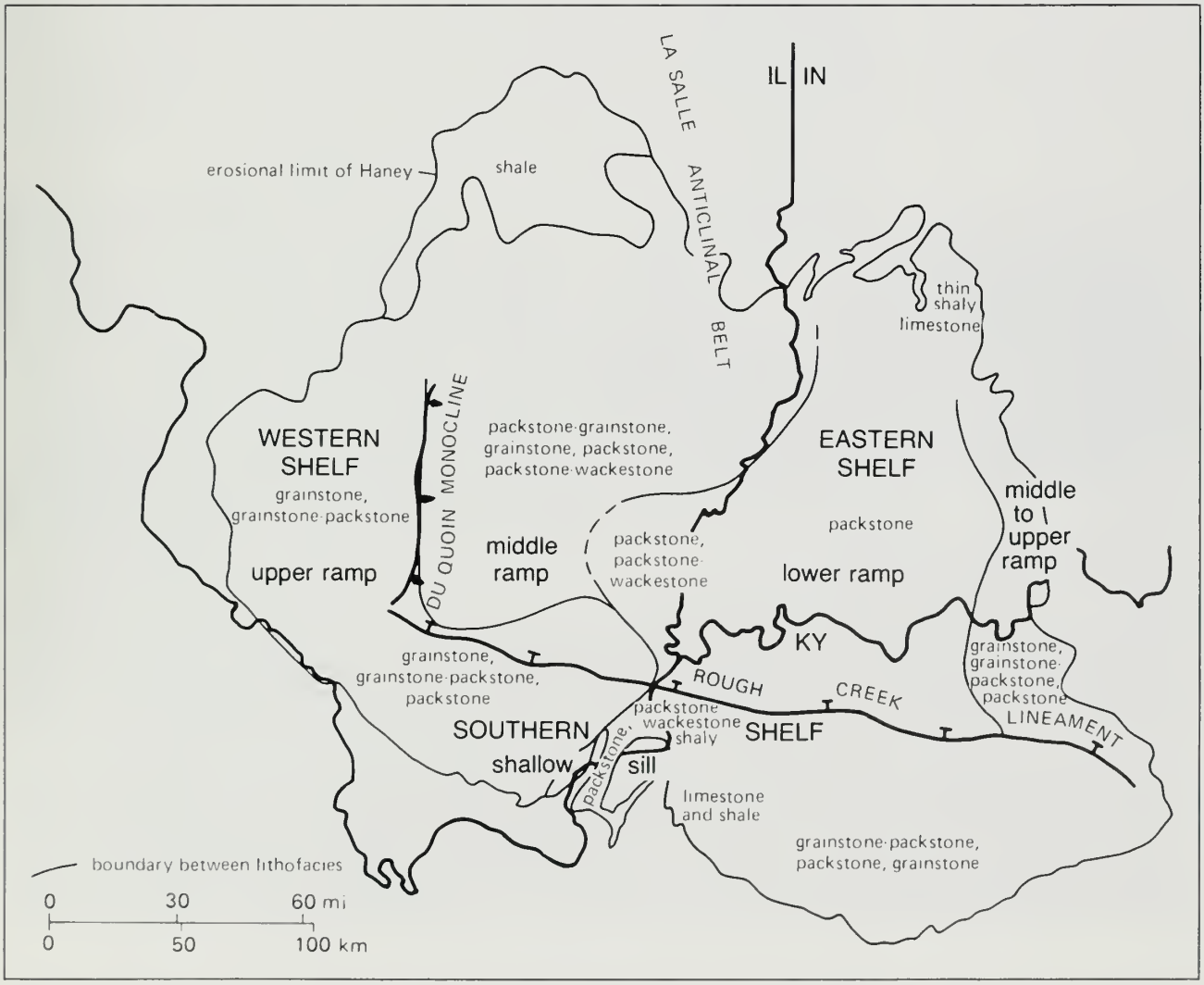


*Figure 10* *Lithofacies and depositional environments of the Haney Limestone and their relation to structural features in the Illinois Basin. Lithofacies are presented in order of abundance in each area.*

Lithofacies of the Haney Limestone become generally less muddy laterally and vertically updip toward the eastern edge of the Eastern Shelf, indicating shallower conditions — middle to upper ramp — shoreward and through time. Facies relations are well represented in outcrop along the eastern edge of the shelf in Indiana. There the lower part of the Haney is commonly a medium-bedded dolomitic packstone or grainstone-packstone, and the upper part is commonly a thick-bedded to massive, crossbedded, oolitic skeletal grainstone (typical of oolitic bars) with large inter-bar lenses of dolomitic wackestone and packstone (fig. 11).

Toward the north end of the Eastern Shelf, limestone in the Haney thins and grades to shale (fig. 10). This indicates reduced water agitation and/or suffocation of carbonate production due to fine siliciclastic influx. The area may represent an intertidal mud flat. All along the north end of the basin basal Pennsylvanian sandstone channels cut into the Haney and Fraileys/Big Clifty.

### Central Part of Basin

**Fraileys/Big Clifty** In the central part of the Illinois Basin, the Fraileys is dominantly shale, with thin, laterally discontinuous wackestone and packstone beds that generally occur near the top of the formation (fig. 9). These sediments represent deposition in relatively quiet to moderately agitated water, probably a lower ramp environment distal to the sediment source. Limestone occurrence in the upper Fraileys represents reduced influx of siliciclastics to the area, as seen on the Eastern Shelf, permitting local carbonate production in the latter part of Fraileys/Big Clifty deposition. Isolated thin sandstone lenses are present in the west-central part of the basin in Illinois (fig. 9). These may be tidal bars, as on the Eastern Shelf, or more likely, they may be turbidites (Kepferle, 1977) or tempestites (Nelson, 1982) because they are downslope of and removed from areas of sandstone deposition to the north on the Eastern Shelf.


*Figure 11* *Lenses of dolomitic wackestone and packstone (d) within oolitic skeletal grainstone from the Haney in Crawford County, Indiana (northwest roadcut at intersection of I-64 and IN Hwy. 37). Formations pictured, from base up, are Big Clifty (BC), Haney (Hy), and Hardinsburg (Hg), which forms slope at top.*

Sandstone occurs in the shale to the north in a band from Indiana west to Effingham and Clay Counties, Illinois (fig. 9). This sand presumably was transported to the area by a subsidiary channel of the Michigan River (fig. 7). In the northernmost part of its extent, the Fraileys consists only of shale (fig. 9). This may represent an intertidal mud flat at the distal, restricted end of the basin (Read, 1980). Siliciclastic influx and restricted conditions presumably shut off carbonate production in the northernmost area.

An unusually thick mass of Beech Creek Limestone in southern Edwards County, Illinois (fig. 6), reaches a maximum thickness of about 80 feet. It is highly irregular in thickness and extends in a northeast-southwest direction for more than 3.5 miles (5.6 km). On the basis of electric log correlations using higher and lower units in the Chesterian, the upper part of the limestone body appears to be time-correlative with lower Fraileys Shale.

**Haney** In the southern end of the central part of the basin, the predominant lithofacies in the Haney are lower ramp packstone and some packstone-wackestone as on the western part of the Eastern Shelf (fig. 10). Apparently basinal depths of at least 100 feet (30 m) where carbonate mudstone deposition would predominate (Wilson, 1975; Read, 1980) were not reached in the Illinois Basin during this time. West and north of the lower ramp area, throughout much of the rest of the central part of the basin, The Haney Limestone is characterized by (in approximate order of abundance) packstone-grainstone, grainstone, packstone, and packstone-wackestone (fig. 10). The range of lithofacies suggests that this is an intermediate setting between the relatively low-energy lower ramp to the east-southeast and the relatively high-energy upper ramp farther west on the Western Shelf.

Toward the northeast of the middle ramp area, the upper part of the Haney grades from a grainstone-packstone in the south to a grainstone in the north (fig. 6). This transition reflects a change from middle ramp in the south to upper ramp in the north and coincides with the position of the La Salle Anticlinal Belt. Because facies changes are subtle and occur over broad distances, relief along the structure is believed to have been low. Further evidence of relief along the structure at this time is a gradual depositional thinning of the Fraileys/Big Clifty Formation from southwest to northeast onto the high side of the monoclinal feature.

Limestone in the Haney thins and grades to shale toward the north end of the middle ramp (fig. 6), as it does on the Eastern Shelf. These fine siliciclastics were derived either from a small channel of the Michigan River or from drainage off the Wisconsin and/or Transcontinental Arches. They may also have been transported from offshore by tidal currents.

### Western Shelf

**Fraileys/Big Clifty** Limestone in the Fraileys increases abruptly on the Western Shelf, which is separated from the central part of the basin by the Du Quoin Monocline (fig. 9). Here laterally discontinuous, relatively thick limestone beds are interbedded with shale throughout the Fraileys. For example, limestone in a quarry in St. Clair County, Illinois, consists mostly of grainstone and packstone, some oolitic. Distribution and lithologic character of limestone bodies on the Western Shelf suggest that they may have been bars formed by wave or tidal currents on a shallow marine shelf or upper ramp where water agitation was relatively high — above effective wave base. The abundant shale interbedded with the limestone lenses indicates continued siliciclastic influx and suspension sedimentation between and behind carbonate shoals.

The Fraileys-Haney interval thickens by about 10 feet (3 m), about 10 percent of its average thickness, on the downdip east side of the Du Quoin Monocline in Franklin County. This thickening and the fact that the boundary between

upper ramp conditions on the Western Shelf and middle ramp conditions to the east coincides with the Du Quoin Monocline indicate topographic relief along the monocline during Fraileys-Haney deposition.

Absence of proximal siliciclastic facies in the Fraileys on the Western Shelf and a decreased thickness of siliciclastics compared to areas to the east is consistent with an easterly sediment supply by the Michigan River and precludes the possibility of a major sediment supply to the Illinois Basin from the Ozark Dome and Transcontinental Arch to the southwest, west, or northwest.

**Haney** The predominant lithofacies in the Haney on the Western Shelf are grainstone and grainstone-packstone, which are cleaner than facies to the east in the middle ramp setting of the central part of the basin (fig. 10). During Haney deposition, this area continued to be upper ramp, above wave and current base level. In places, lower limestones in the Haney on the Western Shelf grade into calcareous shale east of the Du Quoin Monocline for several miles before limestone is reestablished on the middle ramp of the central part of the basin. Upper limestone beds on the east edge of the Western Shelf extend progressively farther east with time and are ultimately continuous with limestone on the middle ramp in the central part of the basin, indicating progressive reduction in relief through time. A pronounced shelf edge never developed along the monocline.

### Southern Shelf

**Fraileys/Big Clifty** On the western part of the Southern Shelf, west of Hardin County, Illinois, shale of the Fraileys includes laterally discontinuous limestone beds that are intermediate in carbonate mud content and in thickness between relatively thick shallow-water carbonate lithofacies on the Western Shelf and thin, deeper water carbonates to the north in the central part of the basin (figs. 9, 6). Farther east in Hardin County and westernmost Kentucky, in the central part of the Southern Shelf, carbonates in the Fraileys/Big Clifty are somewhat cleaner, consisting of skeletal grainstone, skeletal packstone (crossbedded in places), grainstone-packstone, and oolitic grainstone; siliciclastics are coarser, consisting of laterally discontinuous sandstone beds (fig. 9). This area may have been shallower than the area to the west on the Southern Shelf, and/or it may have been an area of stronger tidal currents that winnowed away fine siliciclastics and carbonate muds and promoted carbonate production.

Facies relations in the Fraileys/Big Clifty on the Southern Shelf indicate that the area was shallower than the area to the north, probably middle to upper ramp, and therefore is interpreted to have been a broad sill on the Illinois Basin ramp. The transition between the two areas was gradual and probably reflected relief along the Rough Creek lineament.

Several intervals in the Fraileys on the Southern Shelf appear to be tempestites. One storm that occurred during deposition of the lower Fraileys in Hardin County is traceable in three cores that cover an area of about 75 square miles (195 $km^2$); lack of data precludes determining the full areal extent of this event. The unit is characterized by large shale clasts occurring in a thin (< 2 feet/0.6 m) calcarenite bed (fig. 12) that has a sharp basal contact. Shale underlies and overlies this unit, indicating a return to prestorm sedimentation.

**Haney** Lithofacies in the Haney on the Southern Shelf are intermediate in carbonate mud content between limestone to the north in the lower and middle ramp areas of the Eastern Shelf and the central part of the basin and limestone in the upper ramp on the Western Shelf, indicating that the Southern Shelf continued to be somewhat shallower than the area to the north. Lithofacies include grainstone, grainstone-packstone, and packstone; grainstone is predominant in the upper part in Illinois (figs. 10, 6).

To the west, the Southern Shelf grades into the upper ramp of the Western Shelf. In the central part in Hardin and southeast Pope Counties, Illinois, and

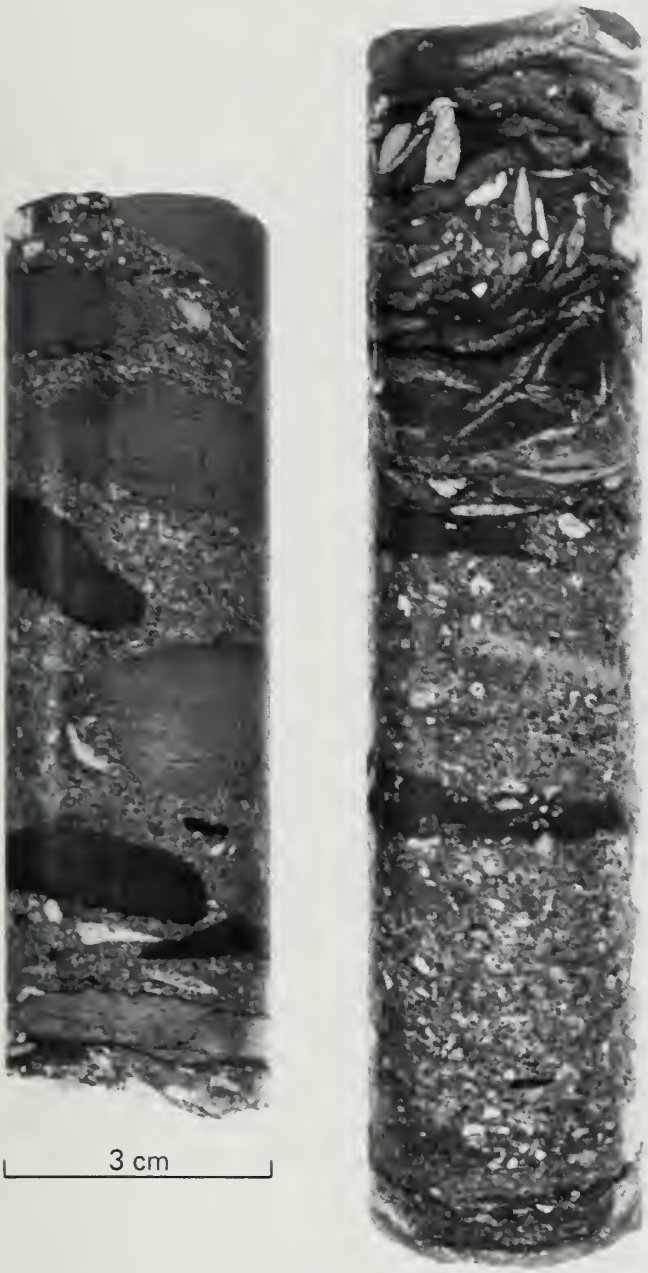


***Figure 12*** *Intraclastic skeletal limestone from tempestite in lower Fraileys in a core from Hardin County, Illinois. Left piece is top. Note textural inhomogeneity and intraclasts of different lithologies.*

in westernmost Kentucky, the upper three-fourths of the Haney becomes increasingly shaly; carbonates eventually pinch out altogether (fig. 10). This suggests that this part of the sill subsided relative to surrounding areas during Haney deposition and became a low area into and through which siliciclastics were funneled from the north-northeast. This area roughly corresponds with some of the thickest sandstone accumulations in the overlying Hardinsburg, indicating establishment of Hardinsburg drainage patterns, including a northward shift of the river system, during Haney deposition. This shift probably coincided with the late Fraileys/Big Clifty-early Haney transgression, which raised regional base level, flooding the delta and lower channels and thereby triggering a major shift of the channel system to the north and northwest. This central part of the Southern Shelf appears to have been affected by siliciclastic influx not evident farther east in Kentucky where limestone in the Haney thickens and becomes essentially nonshaly.

## CONCLUSIONS

This study resulted in the following conclusions about the Illinois Basin during deposition of the mid-Chesterian siliciclastic Fraileys/Big Clifty and carbonate Haney Formations:

- It was a low-angle, low-relief ramp, covered by a shallow epeiric sea with an easterly sediment source during Fraileys/Big Clifty deposition and a northeasterly source during Haney deposition. The entire sequence thickens toward southernmost Illinois near its truncated southern extent. Sandstone in the Fraileys/Big Clifty thickens toward the east; coarser grained carbonates occur in a broad band along the margins of the basin, including the Southern Shelf, and grade downdip and offshore into progressively muddier facies.

- The basin was tidally influenced and had a dominantly westerly paleocurrent direction. Big Clifty sandstone occurs as east-northeast trending offshore tidal bars.

- It was tectonically influenced, as indicated by subtle facies changes and thickness changes across three major structural hingelines.

- It experienced three fluctuations in relative sea level, as determined by the vertical sequence of lithofacies.

Understanding facies distributions in the basin is important because most of the oil that remains to be found in this interval probably occurs in facies-controlled stratigraphic or combination stratigraphic/structural traps. Tidal bars of Big Clifty sandstone on the Eastern Shelf continue to be the most promising target. Where locally porous, the coarse-grained facies of the Haney Limestone on the middle to upper ramp shelf areas around the margins of the basin may yield hydrocarbons. The Big Clifty (Jackson sand) is a significant hydrocarbon-producing zone in Indiana and Kentucky and in Lawrence County, Illinois; the Haney (Golconda lime) was produced only locally on the Western and Southern Shelves in Illinois.

These findings on two formations in the mid-Chesterian can be extrapolated to and tested on the entire Chesterian Series, which is the major oil-producing series in the Illinois Basin. For example, other Chesterian sands may have been tidally controlled; synsedimentary tectonism probably occurred at other times during the Chesterian; potential carbonate reservoirs at other intervals may occur around the margins of the basin, including the Southern Shelf, which was previously considered a deeper basin area.

Future studies can be done to determine porosity and permeability trends in detail and possible correlations of fluctuations in relative sea level to cementation patterns. The regional framework presented here will serve as a basis for local studies in the search of hydrocarbons.

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